Quantum Operations on Optically Addressed $^{171}Yb^+$ Qudits

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Ion-based quantum computers are winning one of the leading positions regarding both the number of qubits and the fidelity of operations [1]. One of the challenges is the scalability since the number of trapped ions in a linear chain is restricted by approximately 50 [2]. There are several approaches on the way to resolve this problem including photonic interconnectors [3], mechanical ion shuffling [4] or increasing the number of addressed internal states. There are numerous theoretical studies demonstrating the advantages of qudit (multi-qubit) systems regarding the number and fidelity of operations.

We study the possibility to use qudits in $^{171}Yb^+$ ion addressed by 435 nm laser field. The narrow quadrupole transition between $^2S_{1/2}$(F=0) and $^2D_{3/2}$(F=2) states with the natural line width of 3 Hz provide a promising platform for realization of multi-qubit states using the Zeeman structure of the D state. In turn, working at visible wavelength allows to use tellurite acousto-optical deflectors with large deflection angle which simplifies the ion addressing.

The full set of one-qubit operations was demonstrated on the two-ion chain in the linear Paul trap assembled at P.N. Lebedev Institute in the frames of Quantum Computing Roadmap [5]. The fidelity of operations reached 90% and was limited by the noise of addressing semiconductor laser. For two-particle entailment we implemented the MS gate on the axial vibrational mode after the ground-state cooling. The demonstrated fidelity of 69% can be further improved in the next trap design with the lower heating rate. The full equivalence of the two-qudit space to the four-qubit space as the scalability example show the perspectives of qudits as the powerful tool for certain computational tasks [6]. As the next step we plan to increase the number of qudits and the operation fidelity to benchmark our system on several standard algorithms.

References

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